

SECTION 7.0      Static Pattern Comparison on the Legend and HMMWV

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## 7.0 Static Pattern Comparison on the Legend and HMMWV

The following set of figures contain static patterns for the complete set of systems tested which have been overlayed for both the automobile (either a Ford Taurus or Ford Thunderbird) and the HMMWV platforms for a number of targets. These encompass all three of the different technologies that we are considering on this program - radar, infrared and ultrasonic. The targets are typically a .3m x .3m aluminum foil, .6m x .6m aluminum foil, and a standing person. The first and last targets are best for detecting differing target types with a reasonable resolution. Included in the plots is the typical day to day variability of the data as referenced to the automobile platform.

A word is in order concerning the methodology of acquiring this data. Given that this is "black box" testing, the edges of the pattern of any system will show the most variability with respect to reporting a target or not. The criteria for reporting a positive detect with a small target (i.e. anything smaller than a motorcycle) was that the sensor system must report a positive detect for greater than 50% of the time.

The plots show a remarkable consistency. The bottom line is that the variation between vehicles is within the limits of variation of system performance over time on the same vehicle. One plot in the enclosed package seems to indicate a fairly large difference between the vehicles. It is the System 'E' with a human target. At present this cannot be explained other than invoking the observation that some systems seem to have extensive variations. Controlled dynamic tests suggest a correlation between the relative scatter of data points on the delay time tests and the overall performance of the sensor system.

Figure 7-A1: System "A" - 0.3m x 0.3m Foil Target

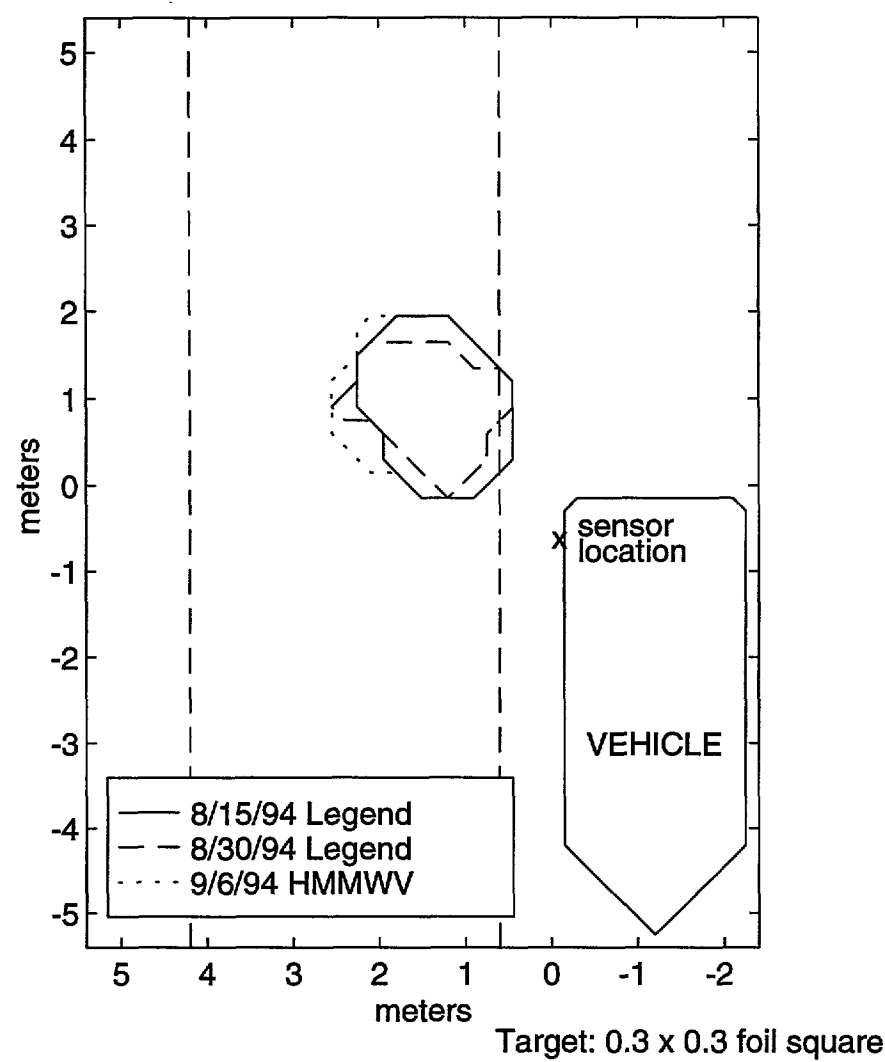


Figure 7-A2: System "A" - 0.6m x 0.6m Foil Target

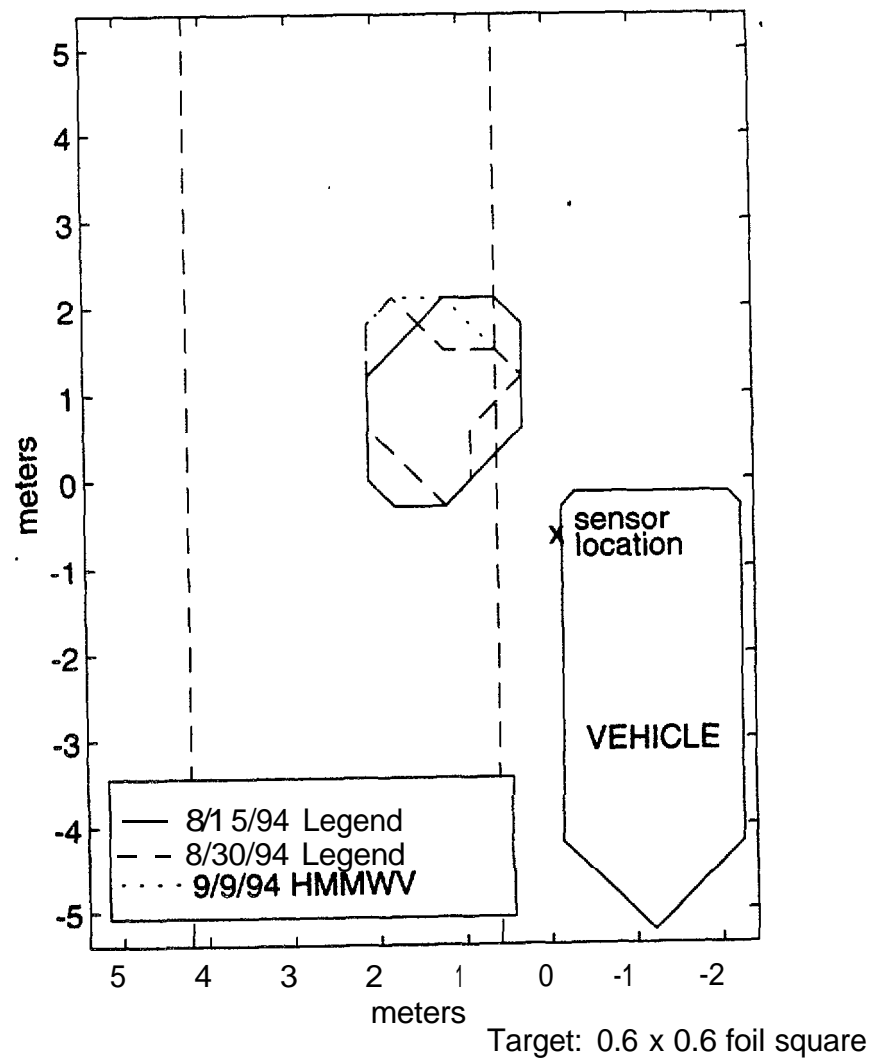


Figure 7-A3: System "A" - Human Target

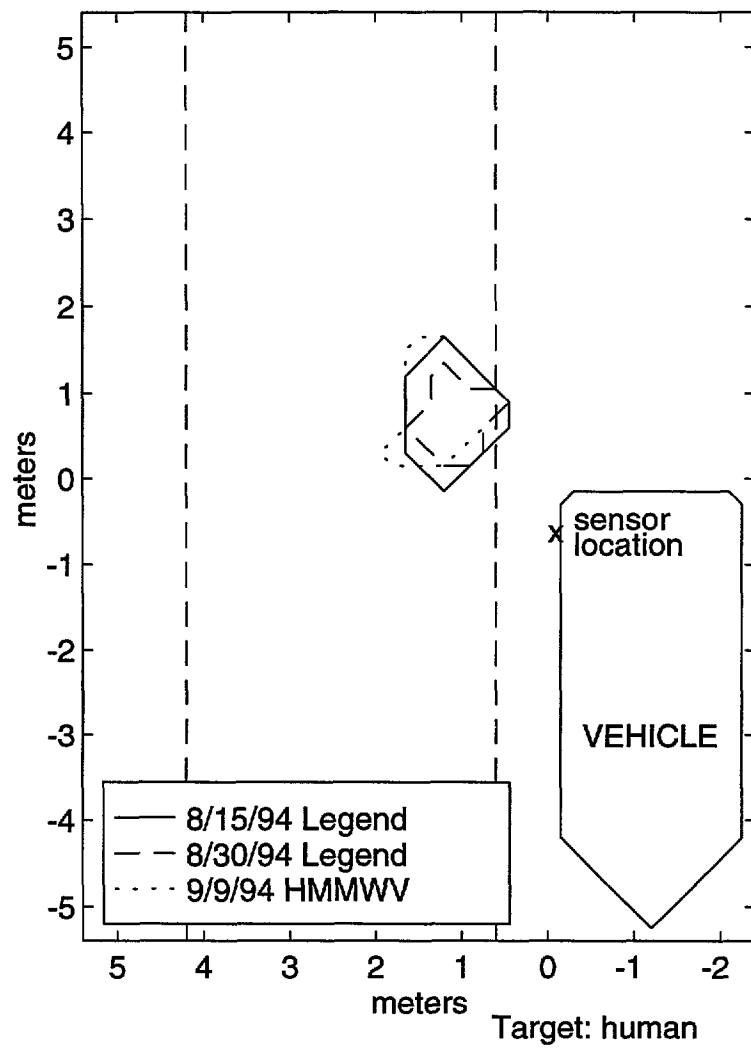


Figure 7-B1: System "B" - 0.3m x 0.3m Foil Target

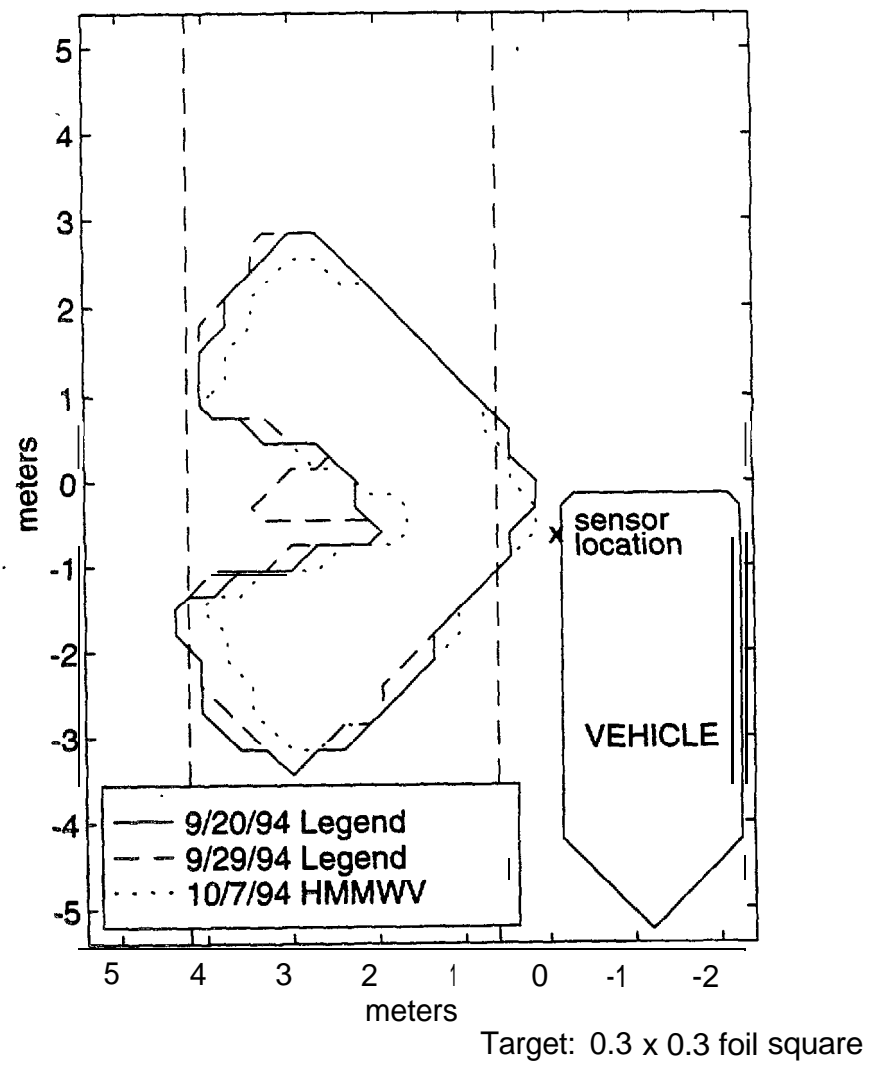


Figure 7-B2: System "B" - 0.6m x 0.6m Foil Target

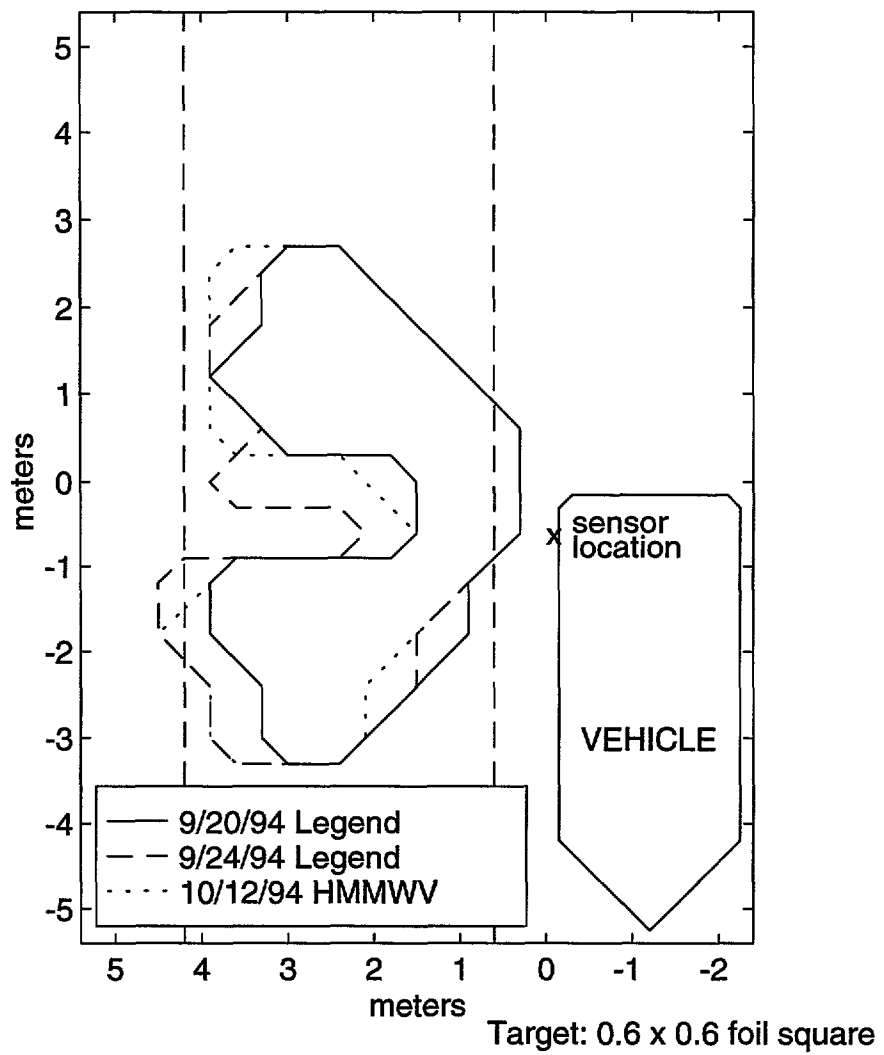


Figure 7-B3: System "B" - Human Target

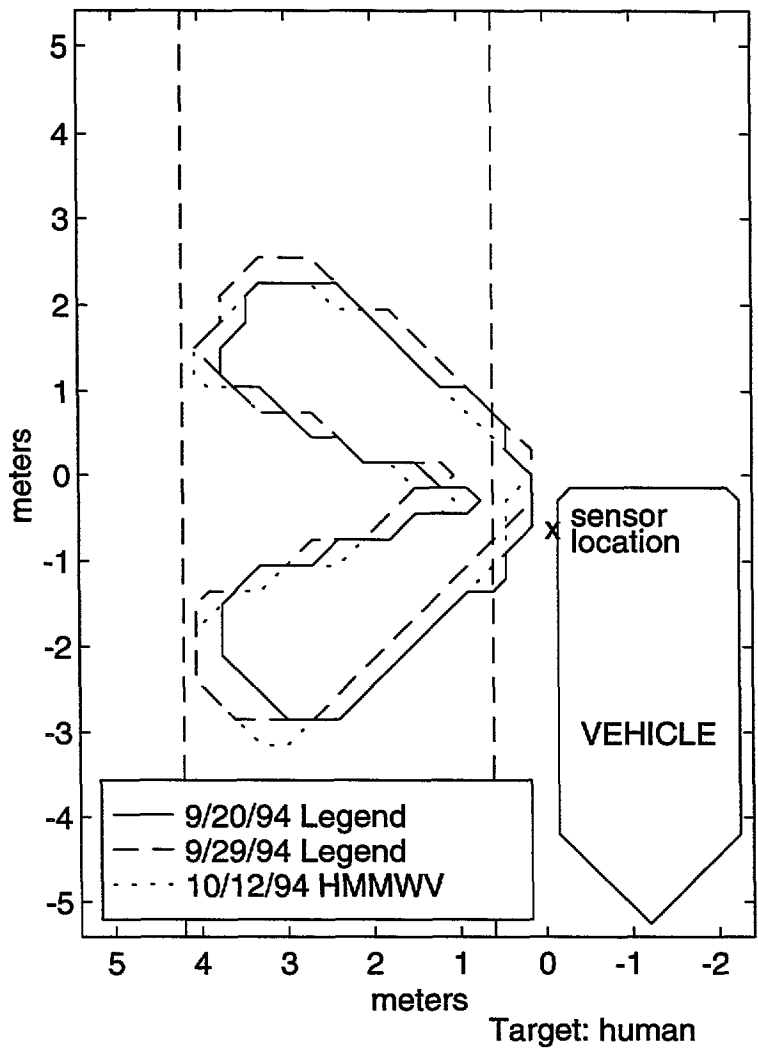




Figure 7-D1: System "D" - 0.3m x 0.3m Foil Target

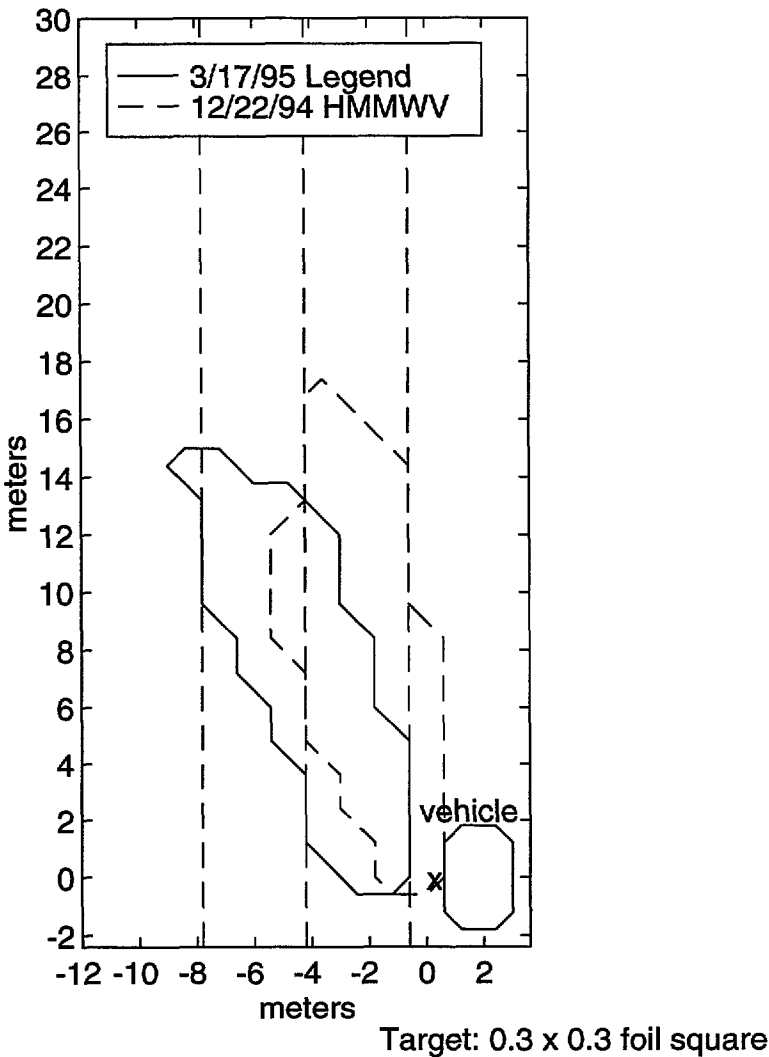


Figure 7-D2: System "D" - 0.6m x 0.6m Foil Target

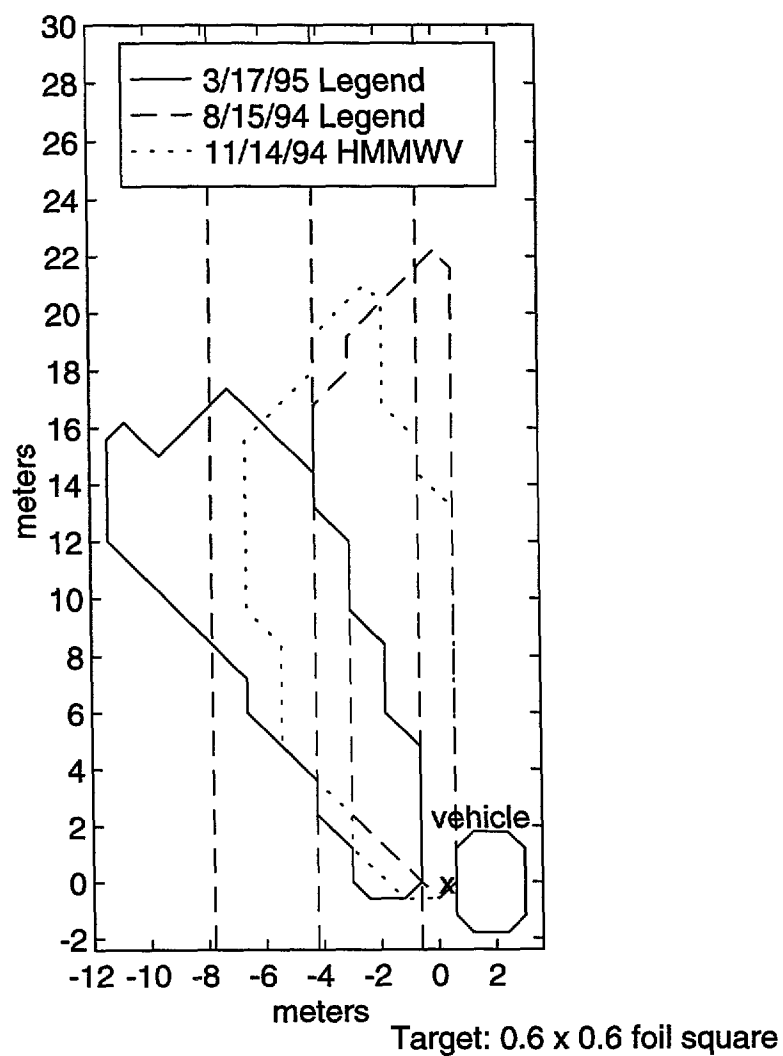


Figure 7-D3: System "D" - Human Target

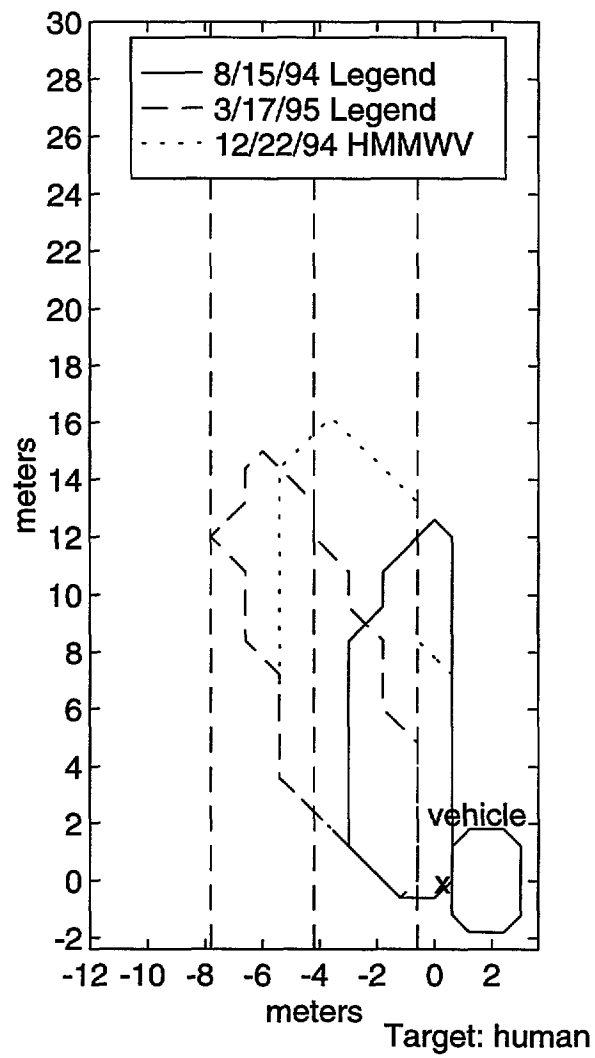


Figure 7-E1: System "E" - 0.3m x 0.3m Foil Target

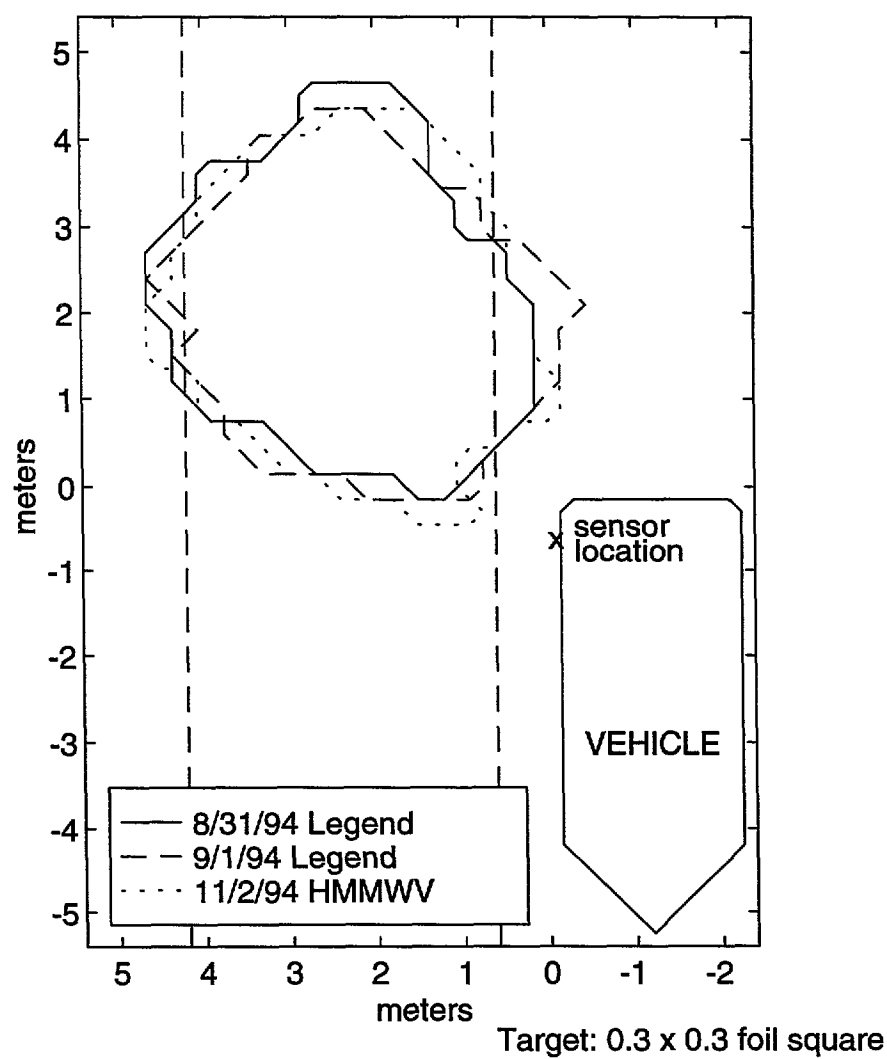


Figure 7-E2: System "E" - 0.6m x 0.6m Foil Target

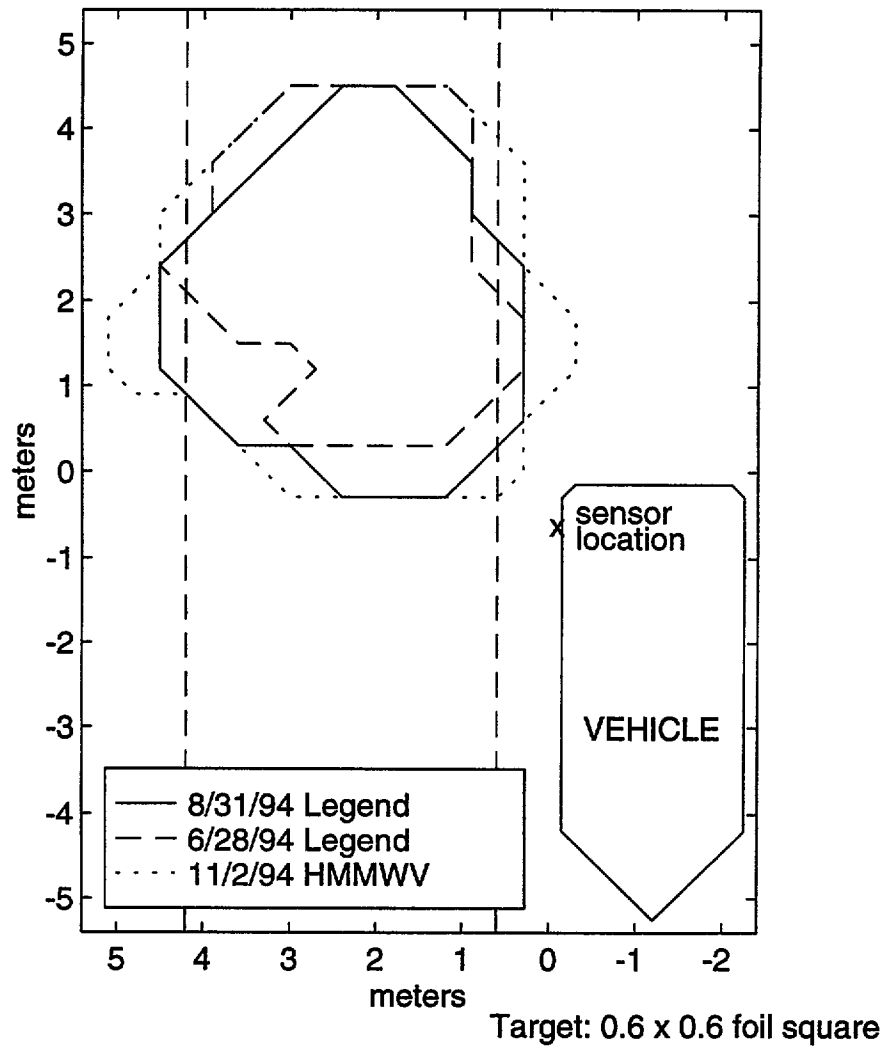


Figure 7-E3: System "E" - Human Target

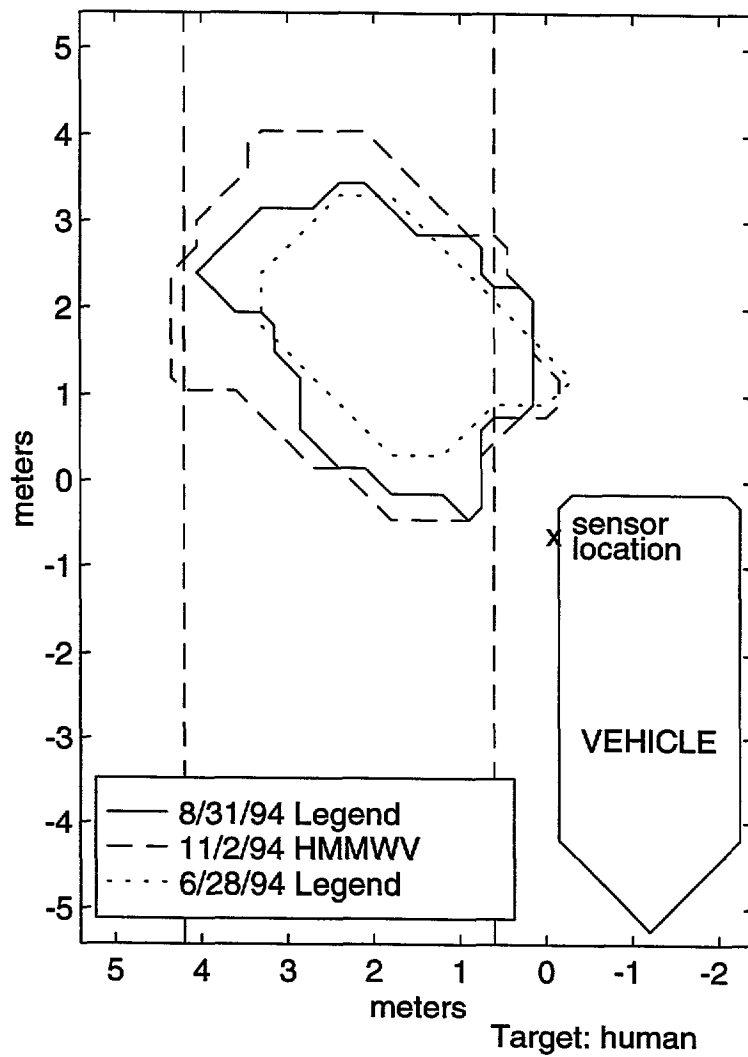


Figure 7-F1: System "F" - 0.3m x 0.3m White Foam Target  
Driver's Side Sensor

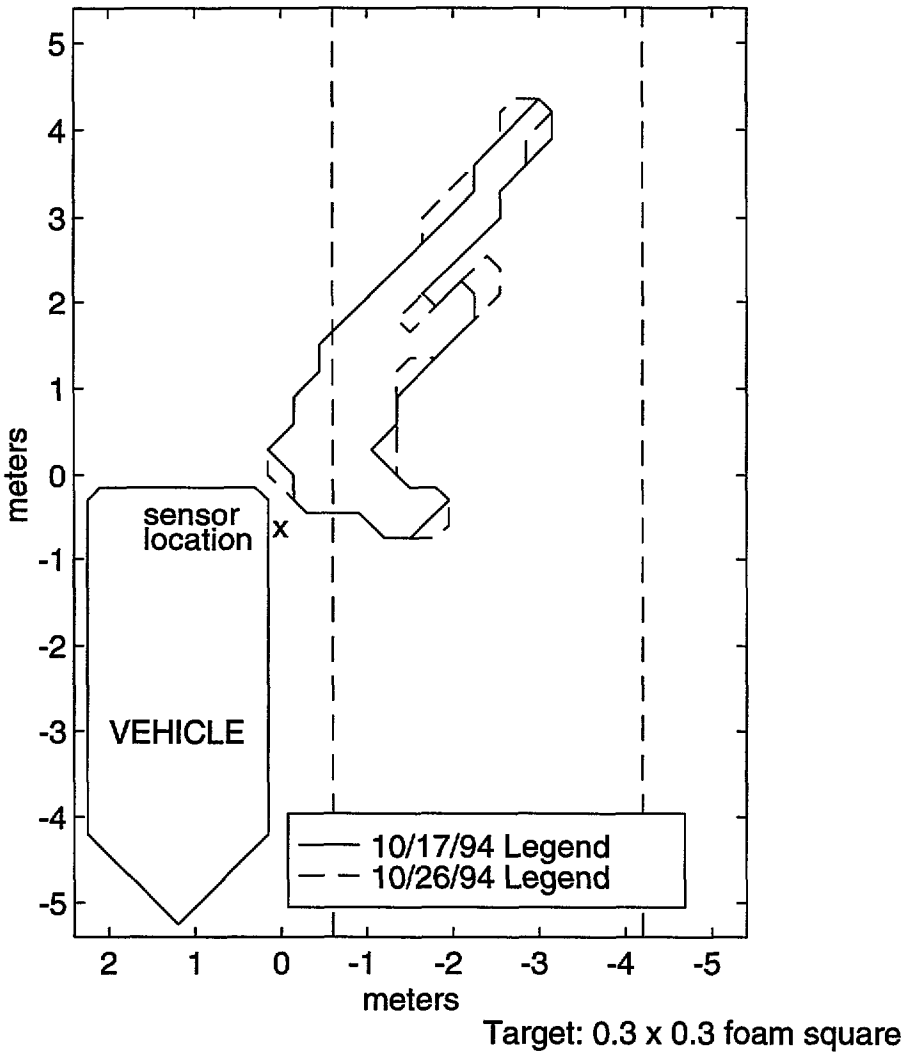


Figure 7-F2: System "F" - Human Target  
Driver's Side Sensor

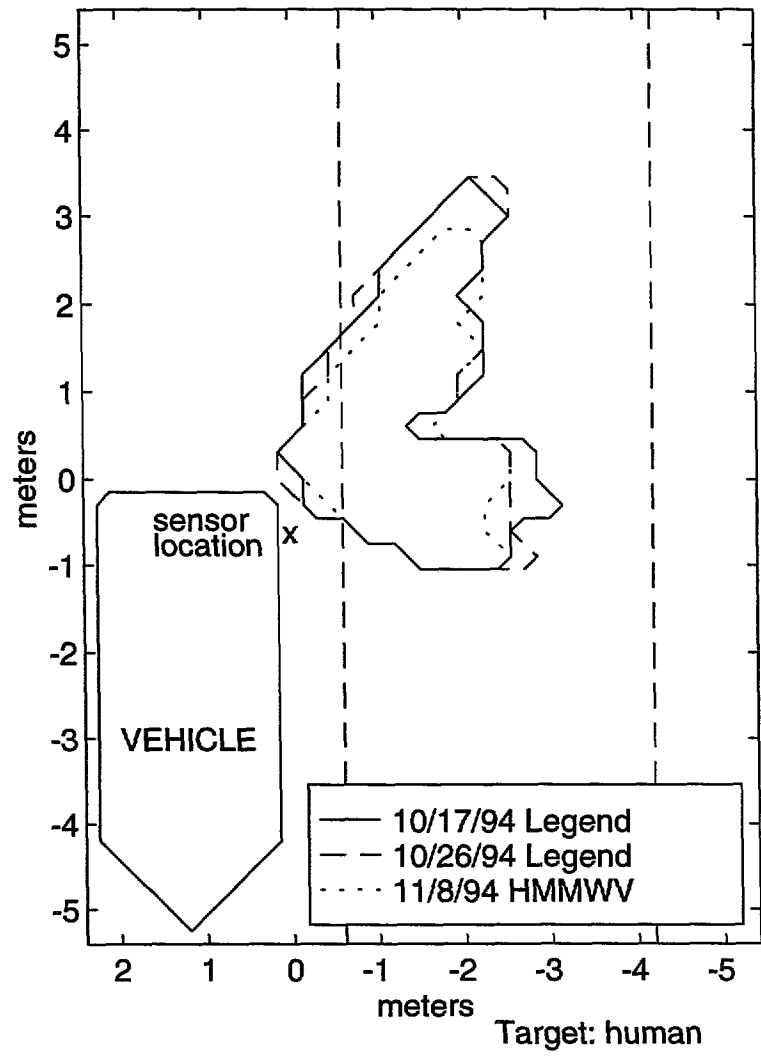




Figure 7-F3: System "F" - 0.3m x 0.3m White Foam Target  
Passenger Side Sensor

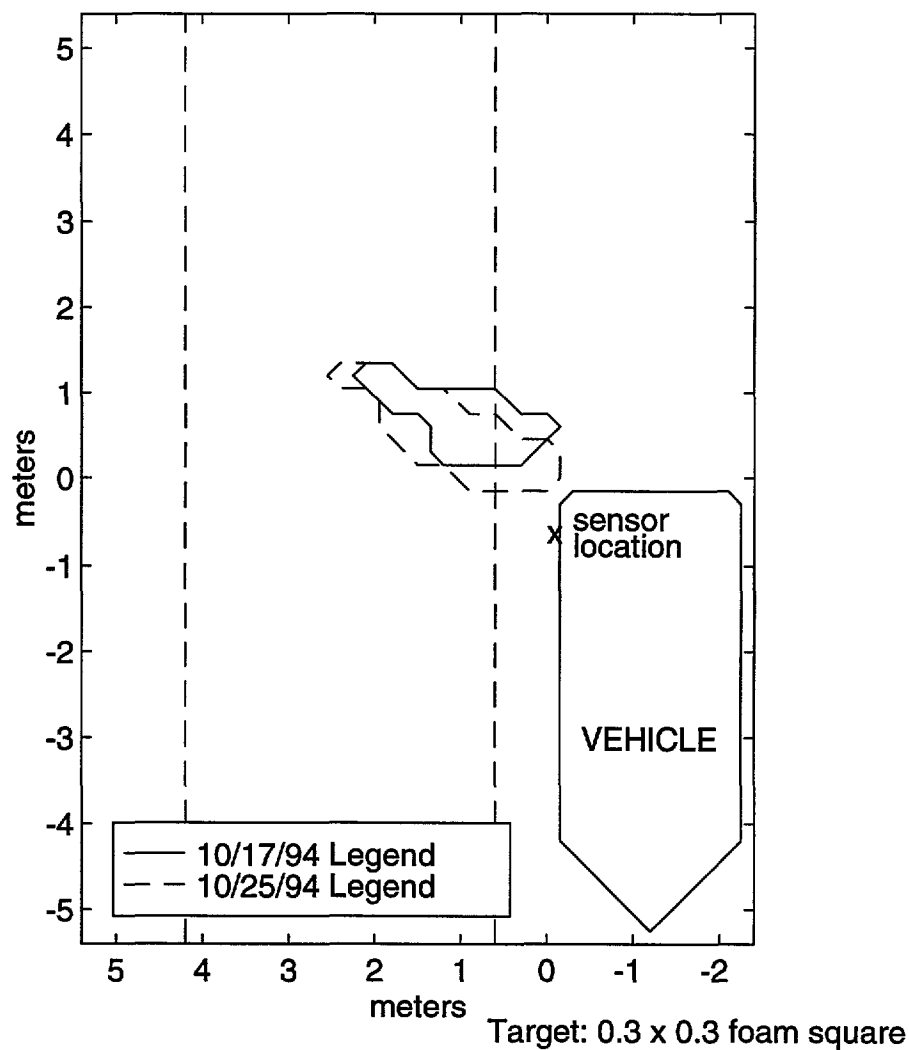


Figure 7-F4: System "F" - Human Target  
Passenger Side Sensor

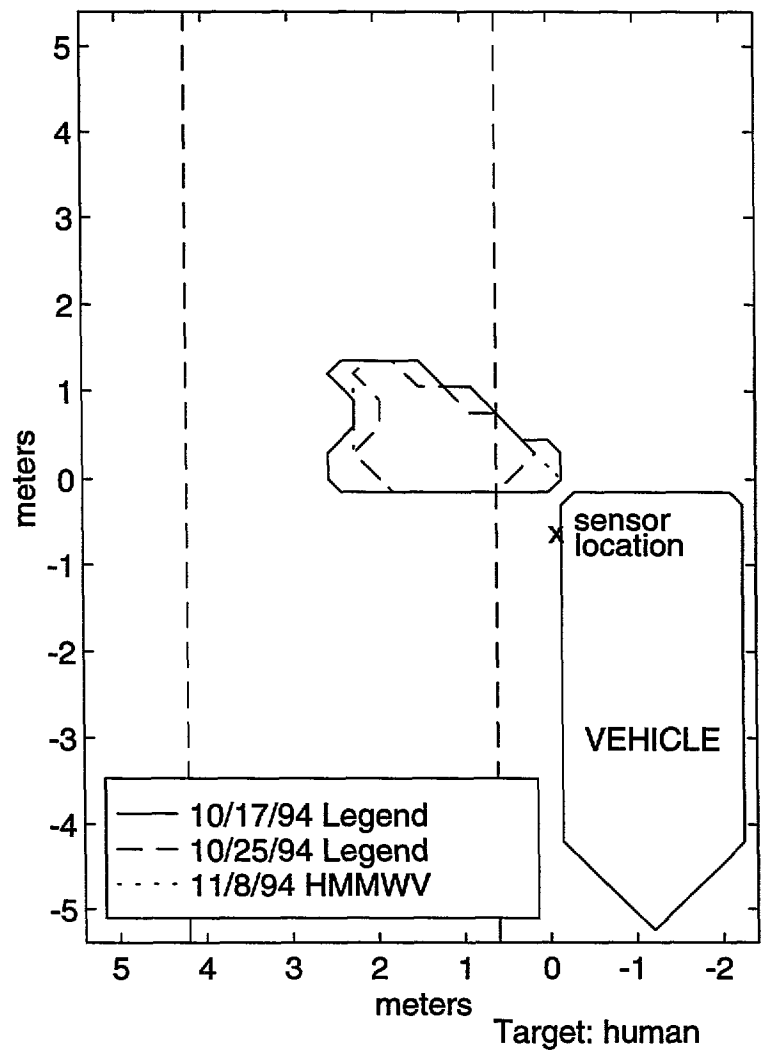


Figure 7-G1: System "G" - 0.3m x 0.3m Foil Target

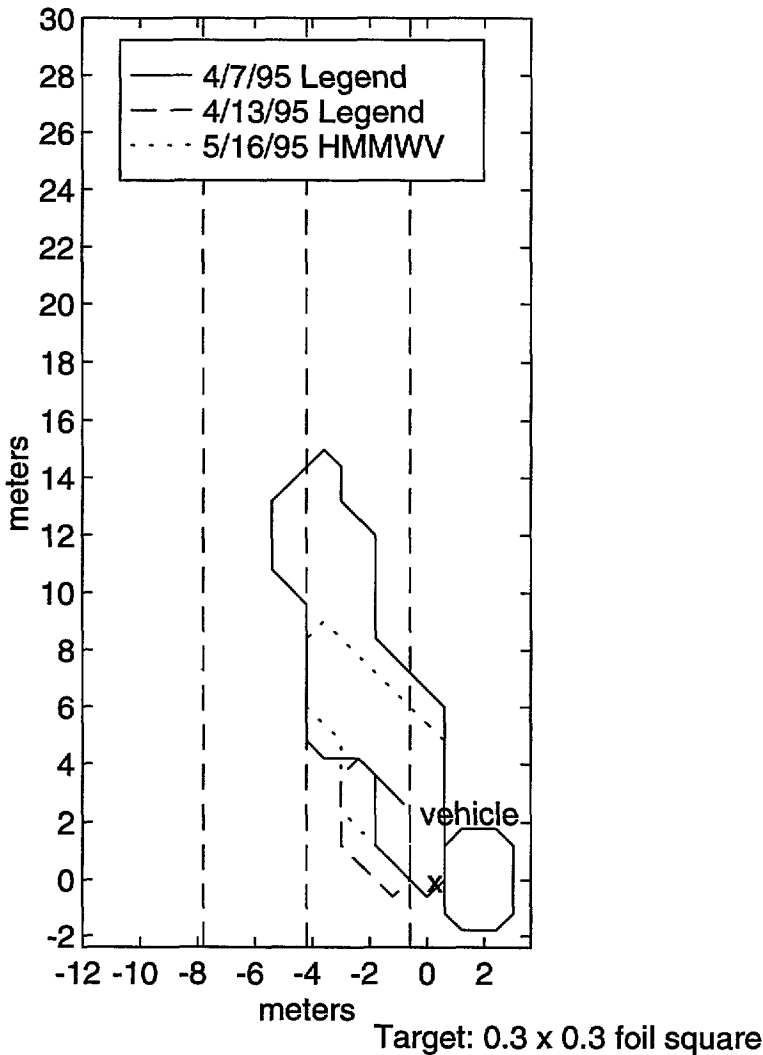


Figure 7-G2: System "G" - 0.6m x 0.6m Foil Target

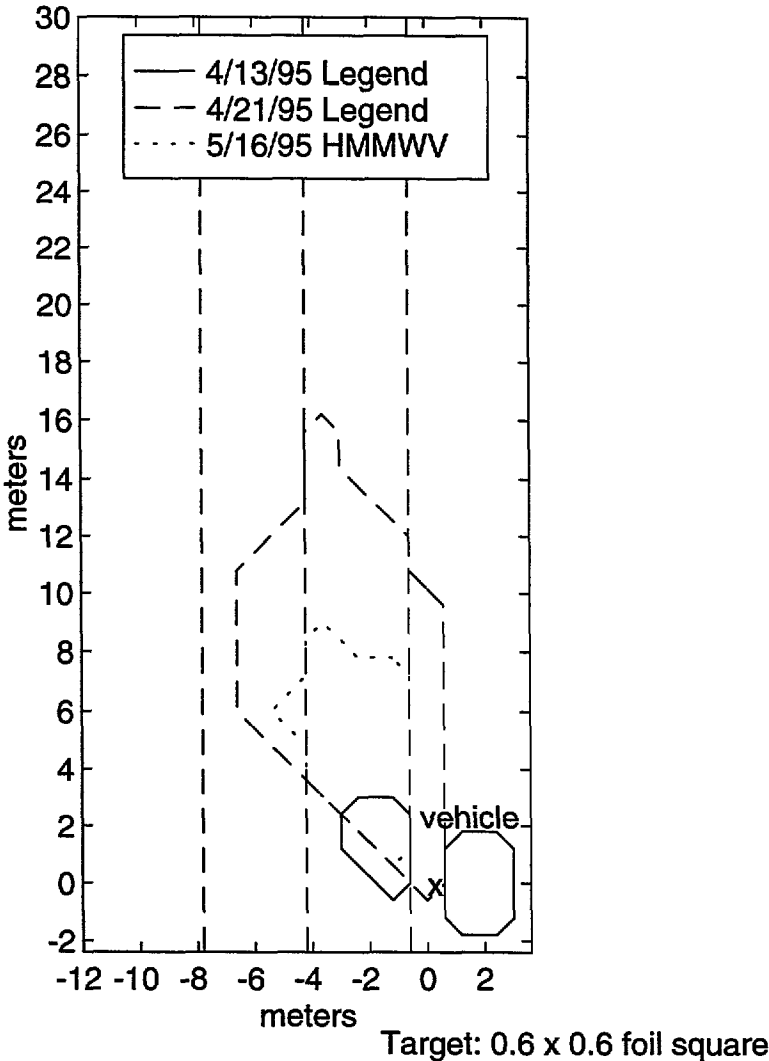


Figure 7-G3: System "G" - Human Target

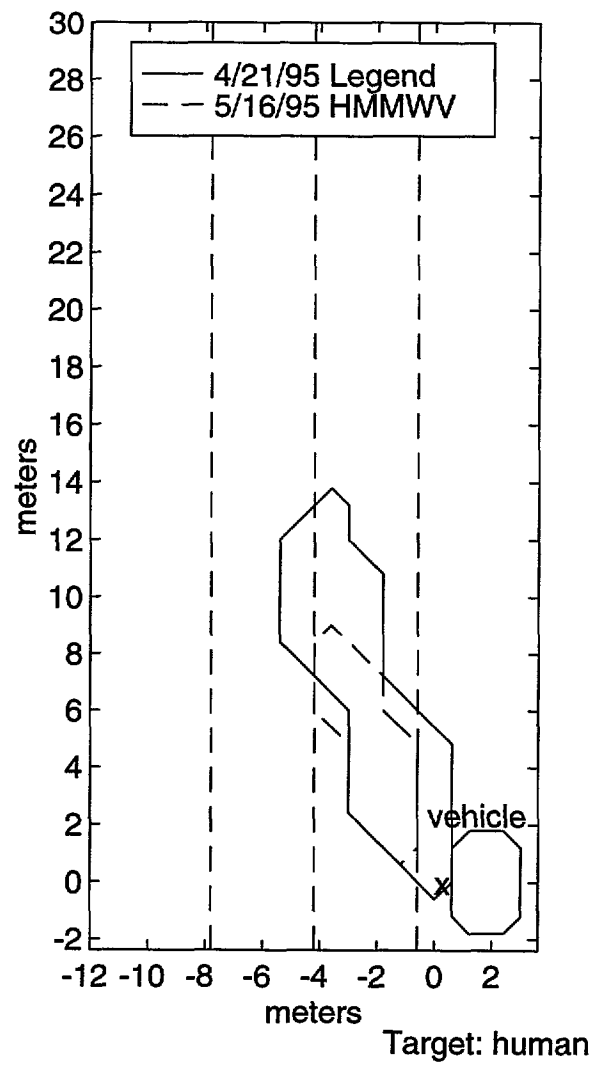


Figure 7-H1: System "H" - 0.3m x 0.3m Foil Target

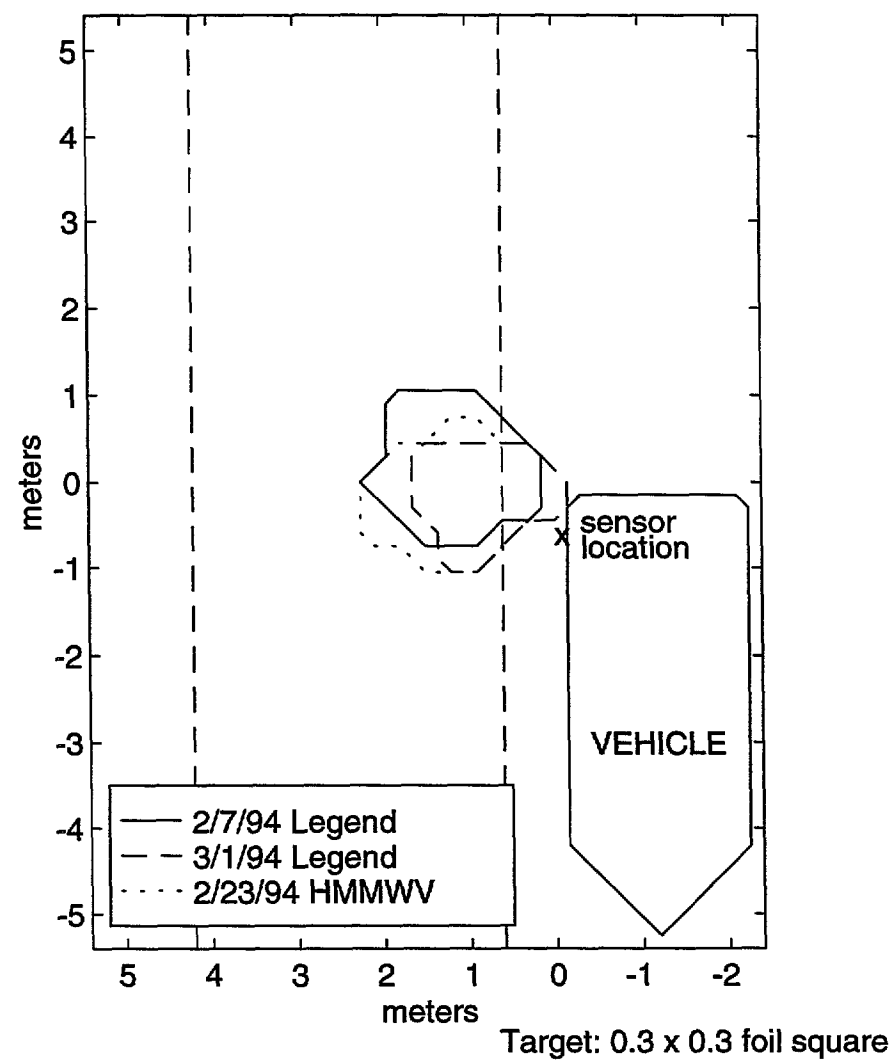
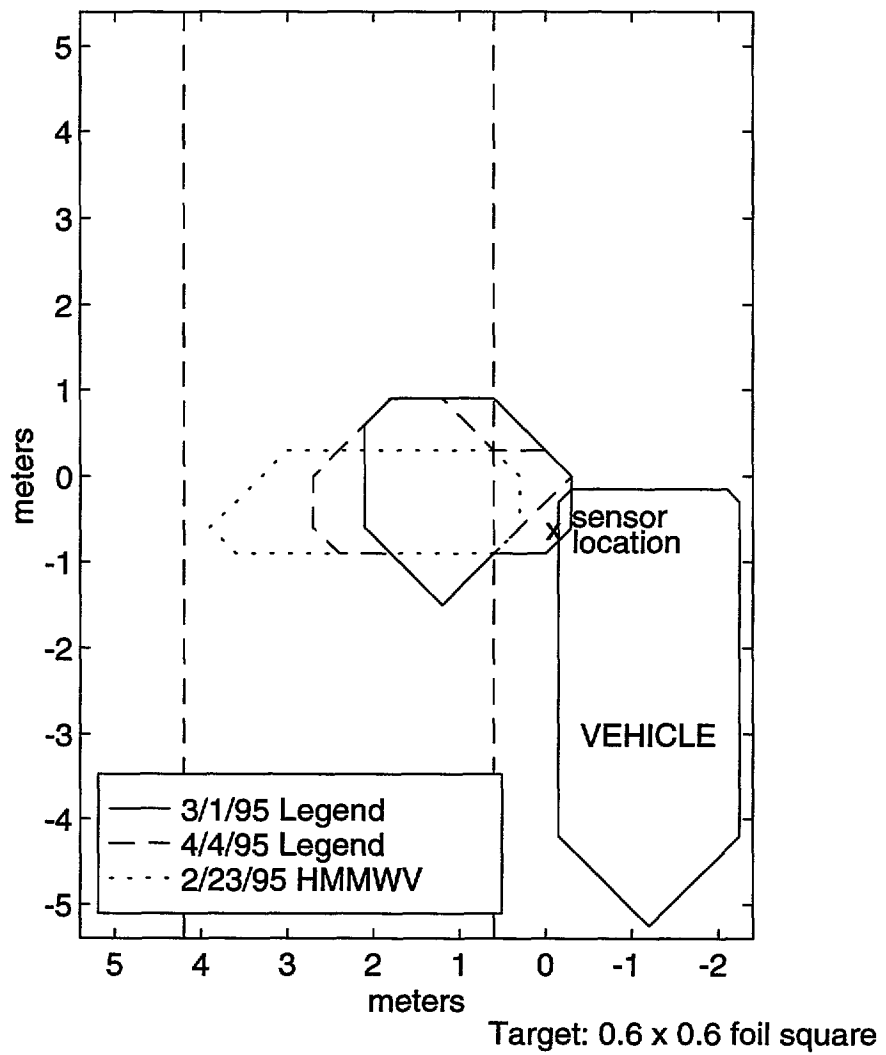


Figure 7-H2: System "H" - 0.6m x 0.6m Foil Target



**Figure 7-H3: System “H” - Human Target**

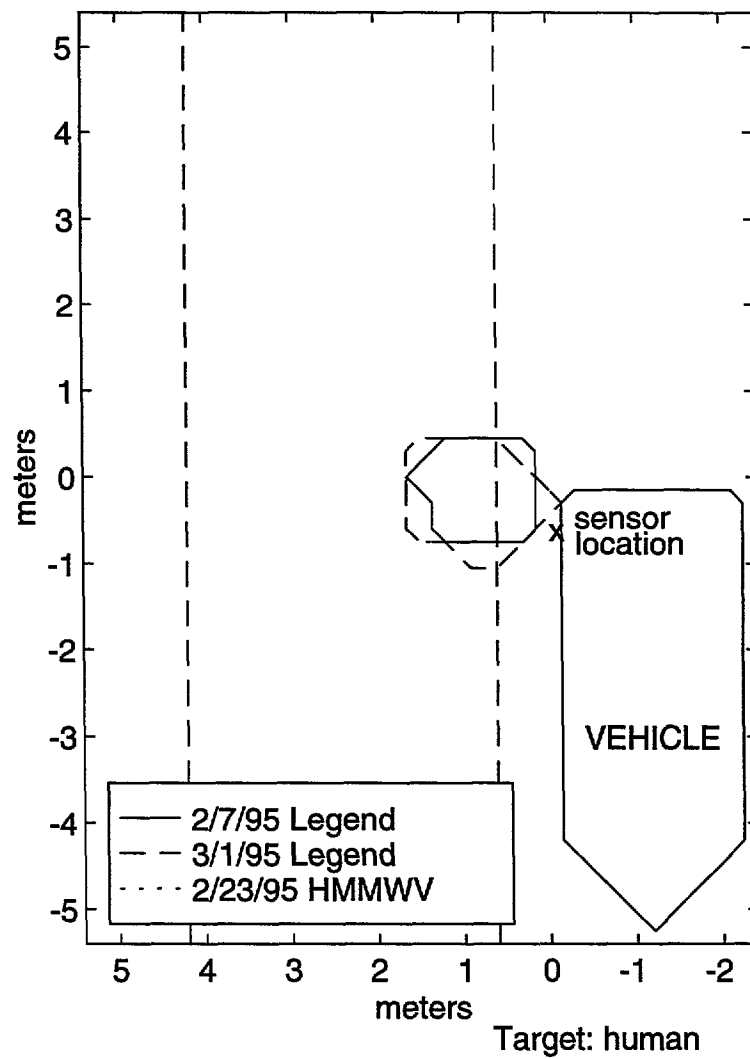




Figure 7-R1: System "R" - 0.3m x 0.3m Foil Target

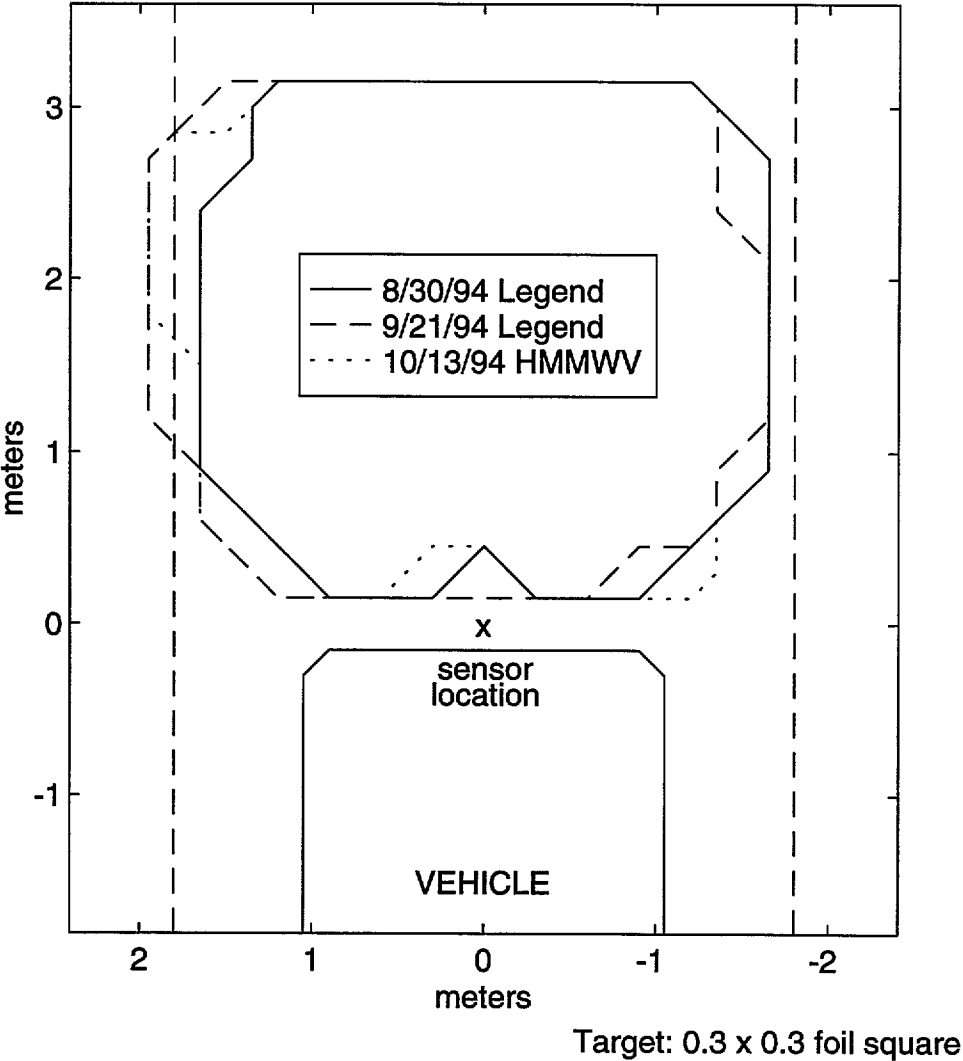
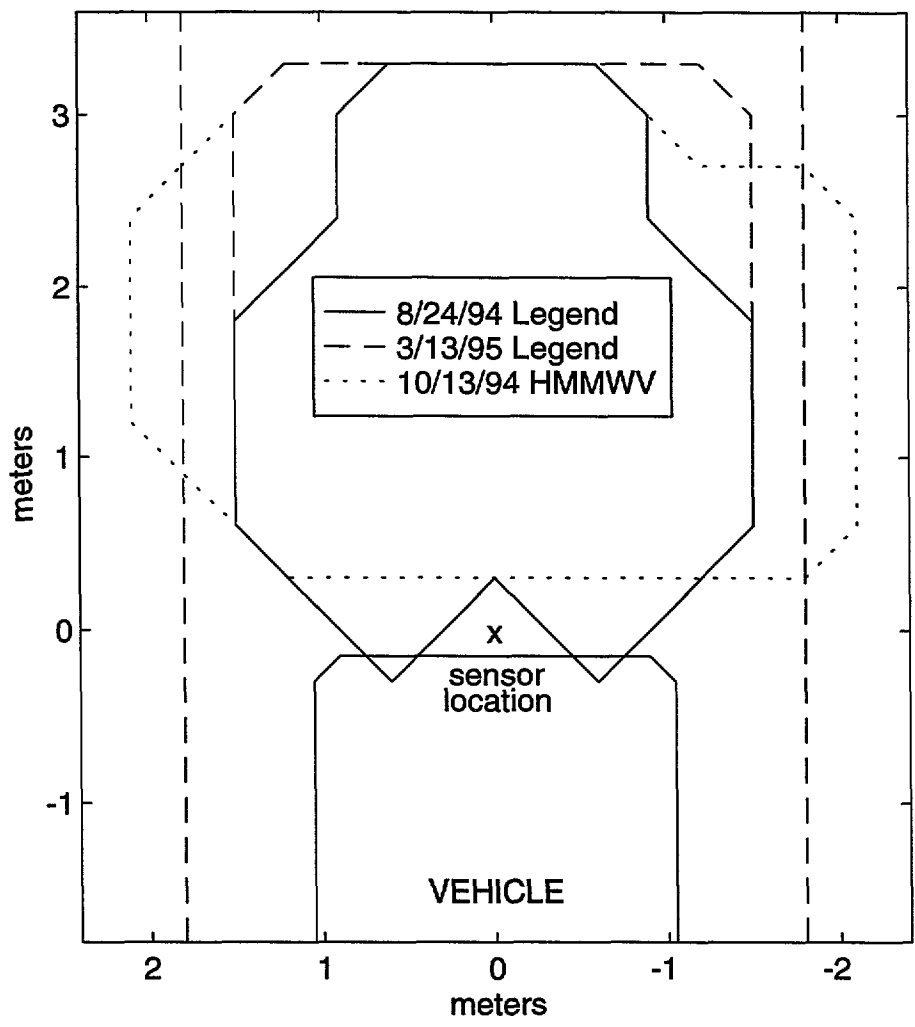


Figure 7-R2: System "R" - 0.6m x 0.6m Foil Target



Target: 0.6 x 0.6 foil square

Figure 7-R3: System "R" - Human Target

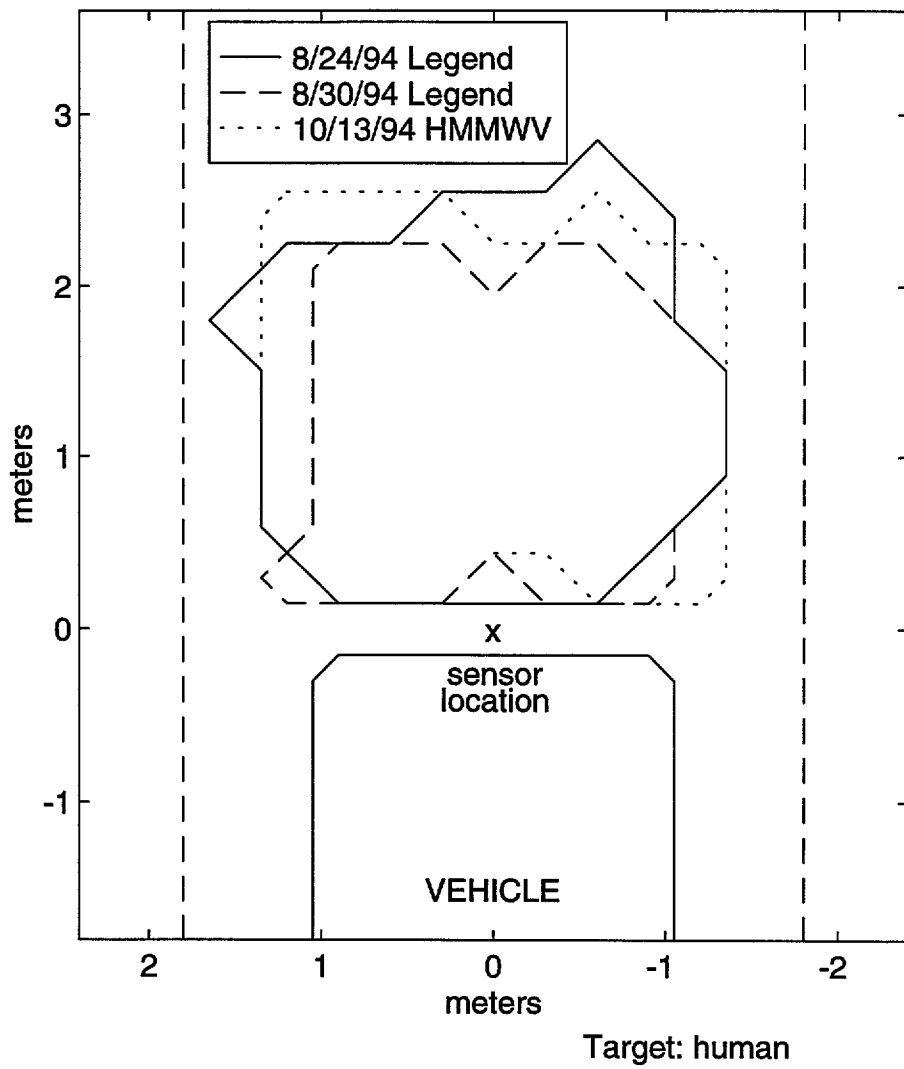


Figure 7-S1: System "S"- 0.3m x 0.3m Foil Target

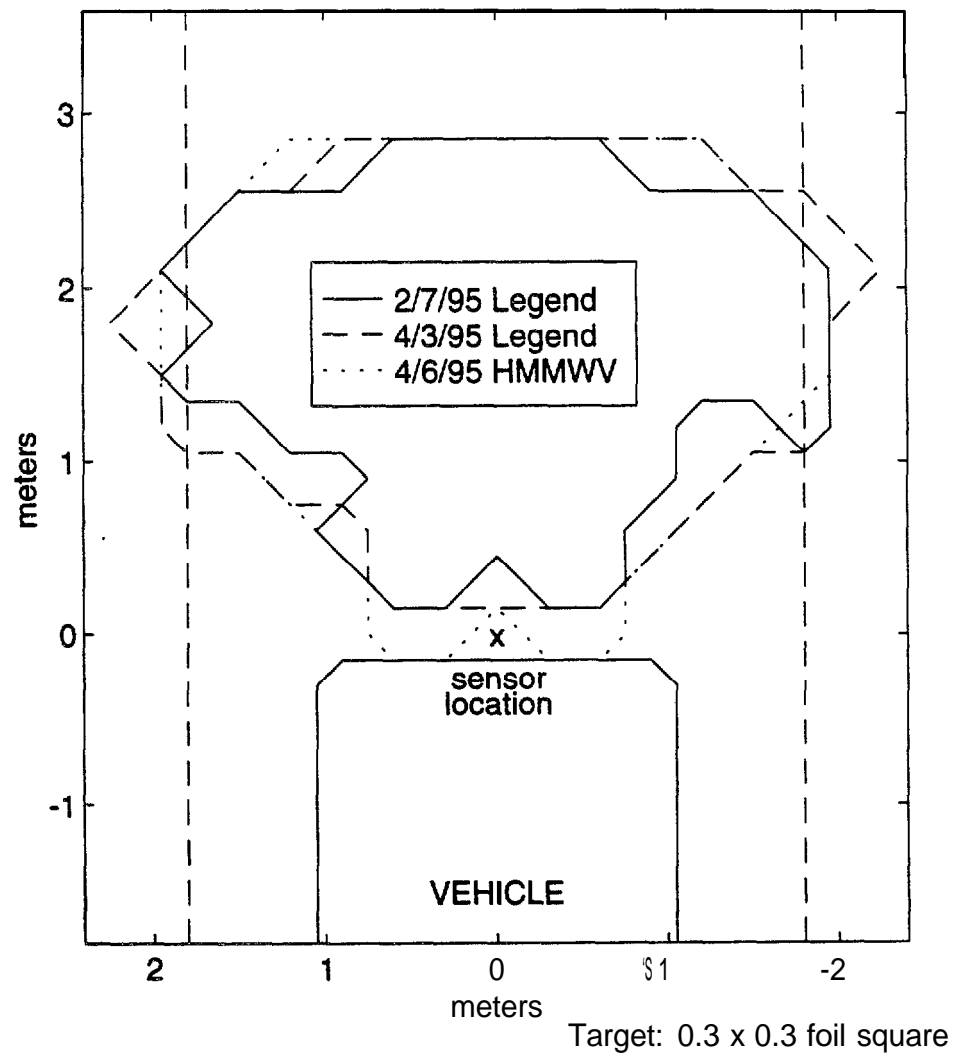


Figure 7-S2: System "S" - 0.6m x 0.6m Foil Target

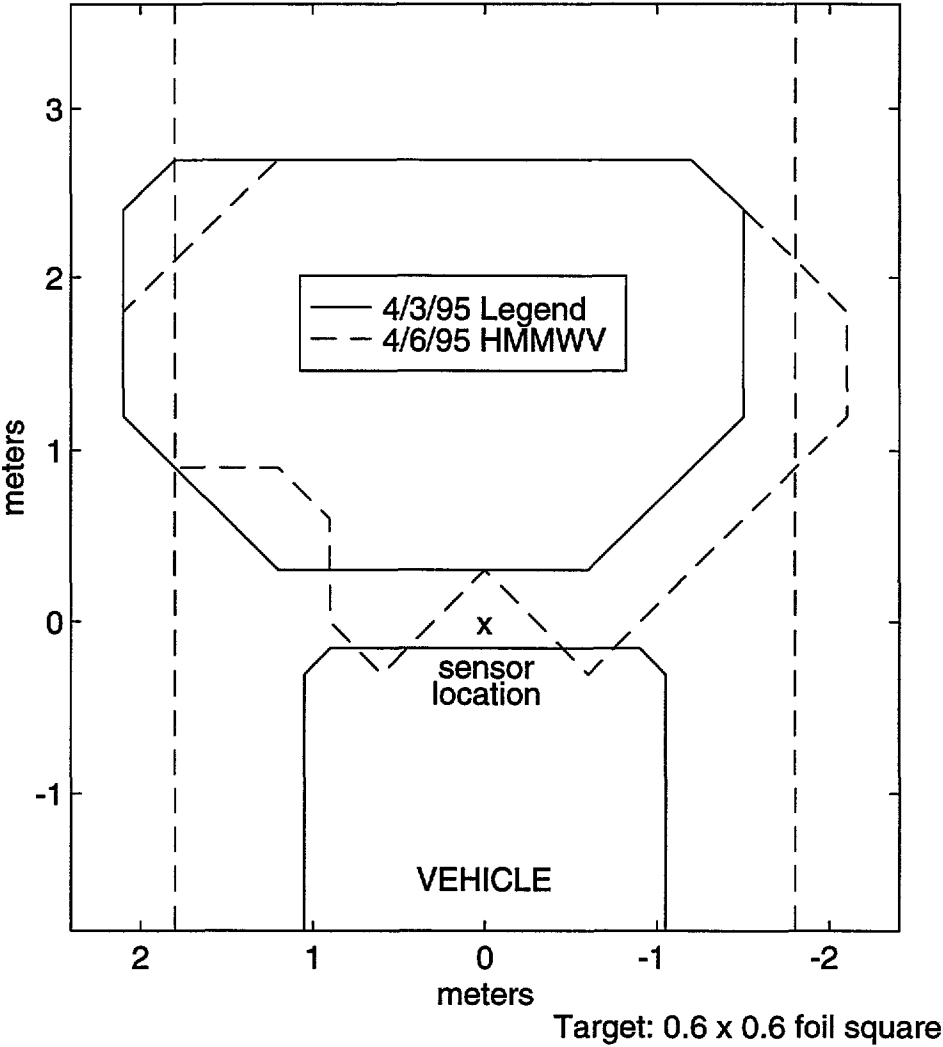
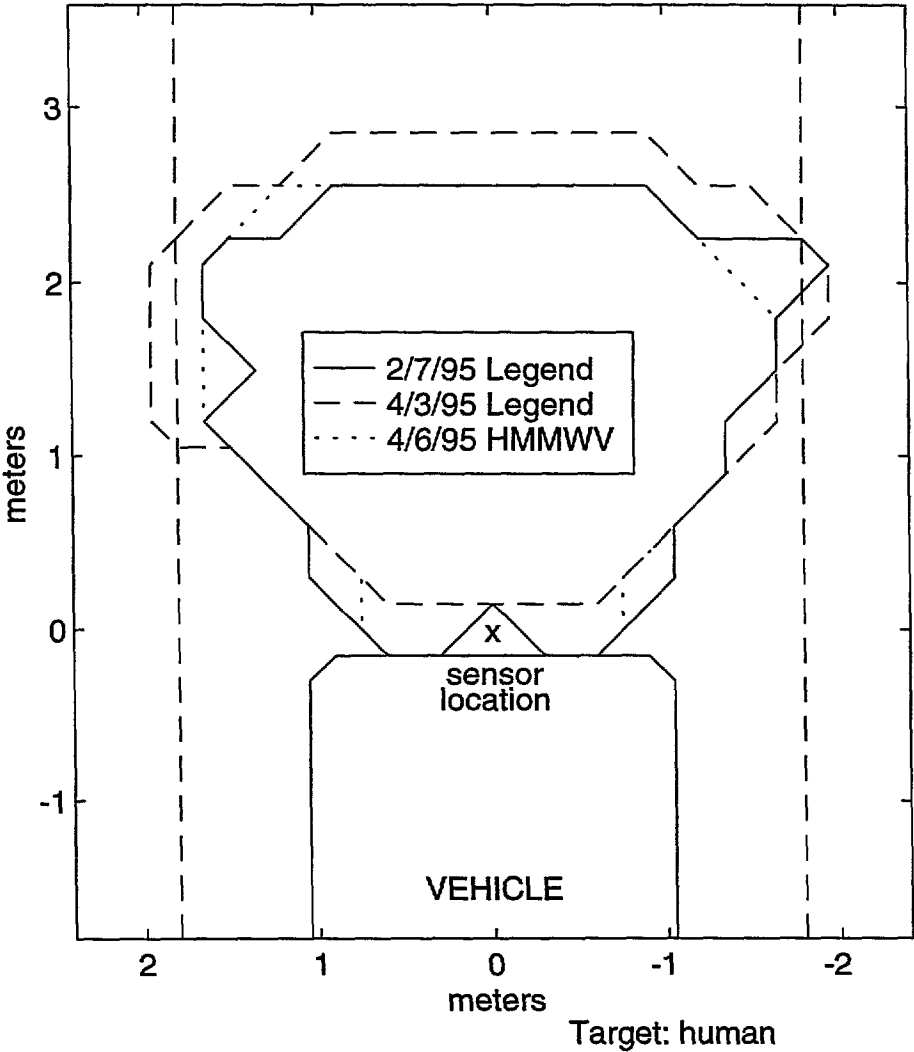


Figure 7-S3: System "S" - Human Target



## 8.0 Conclusion

We have tested a total of 11 collision avoidance systems. Four were for backing: of these four, two were video and two were ultrasonic. The remaining seven systems were lane change systems. Of these, five were microwave radar, one was infrared and the last was ultrasonic. The sensor systems were treated as “black boxes” in that no attempt was made to access interior subsystem components. All performance data was obtained by a series of stimulus/response tests. All dynamic testing was specifically modeled after real world driving maneuvers, using a specially delineated target vehicle so that accurate positional coordinates could be obtained. Finally, the sensor system was taken for a road test, the purpose of which was to expose any weaknesses of the system. It should be noted that in all cases the road test results were consistent with the controlled tests.

Three other general comments can be made. All but one of the systems were characterized by a maximum range of about 5m. The second comment is that all of the systems that provided an obstacle warning (i.e. all the non-video systems) exhibited a large amount of scatter in the data concerning the measurement of delay time. We surmise that the main component of the delay time in any sensor system is the microprocessor time. If this is much longer than the data collection time there will be times when the signal from a potential obstacle is large enough to trigger a warning and other times when it needs to move closer, hence the scatter in the data. These variations of target signature, known as scintillations, are common phenomena, particularly for man-made objects. They can be averaged out if longer observation times are employed. An effort was made to compare the systems on different platforms by also gathering static data using a HMMWV. It was found that the variations between the vehicles was within the day to day variation of the sensor system on the same vehicle. Indeed it would have been surprising if this were not the case, as it should be imperative for a vendor to make any CAS system platform independent.

We have found, in the course of performing these tests, that in any next generation of tests the following improvements would be extremely desirable. First and foremost is that the data reduction and analysis flow needs to be greatly enhanced. The primary obstacle standing in the way of taking more data and making better use of the data already gathered is the labor intensive post processing that must be done. The data flow can be enhanced by two methods: 1) the development of passive ranging algorithms to measure the distance using the video cameras and 2) greater and more creative use of rangefinders that can couple into the existing data acquisition system. Once it is possible to extensively automate the processing of data then the testing can be opened up to more extensive road tests, emphasizing human factors, and fundamental phenomenology of sensors.

Besides categorizing the systems as lane change/merge and backing, the video systems should be categorized separately. These systems are fundamentally different than the other systems in that they make no decisions concerning the presence or absence of potential collision obstacles. The video systems can be thought of simply increasing the field of regard of the driver thus acting as a vision enhancement system.

## 8.1 Lane Change/Merge Systems

Six of the seven systems can be characterized by short range, more appropriate to the limited task of blind spot detector. Three of the systems (B, D and G) advertise the ability to reject stationary targets so as to reduce inappropriate alarms.

We have found the following summary table of performance to be of particular value. Figure 8.1-1 is based upon statistics gathered during the road test and includes a few key performance parameters. In order to have a common basis of comparison for all of the lane change systems, we have treated systems B, D and G as if they had no clutter rejection capability. In Figure 8.1-1 we have treated the inappropriate alarms as if they were true positives (TP). It should be noted that the statistics are not comprehensive. These road tests were conducted one time for a period of approximately one hour. However, as a semi-quantitative measure of performance we have found the True Negative (TN) value to be a valid indicator. Note first of all that those systems with the lowest number of false returns (either positive or negative) are all correlated with the shortest delay time. False positives can be a function of the fact that the detection threshold is set too low and that noise fluctuations will trigger a detection. However false negatives, which have much graver consequences, can be mitigated by a fast processing time, which provides for a greater number of chances for detection. The equation for computing true negative is

$$TN = 1 - (TP + FP + FN) * (\text{latency time}) / (\text{test duration}).$$

It is readily seen that shorter delay time and lower false positives and negatives result in a higher value of TN. This is a rather imperfect scale, especially considering the fact that even the worst system scored a 95%. However as a measure of relative performance it appears to be valid. It remains for further testing to develop an improved version of this scale.

As previously mentioned three of the lane change systems advertise their capability of ignoring ground clutter. Given the way the road test statistics were gathered, no effort was made to catalogue the number of ground objects that the systems did ignore. Instead, we present in the following table (Figure 8.1-2) the tabulated results of “inappropriate” alarms due to ground targets.



Figure 8.1-1

## Road Test Statistics - Side Systems

System	Test Duration (min)	Latency Time (sec)	Persistence Time (sec)	Total # of detects	TP	FP	FN	TN (%)
System "B"	71.8	0.066	.051	76	76"	0	0	99.9
System "F"	58.3	0.042	0.92	163	162	1	2	99.8
System "D"	58	0.52	0.118	93	85"	8	0	98.6
System "G"	73.9	0.62	1.23	129	123	6	1	98.2
System "H"	31.2	0.46	0.54	93	88"	5	0	97.7
System "A"	73.9	1.9	N/A	84	30	54	26	95.3

TP = true positive (system reacts in situations requiring signal)

FP = false positive (system reacts in situation not requiring signal)

FN = false negative (system does not react in situation requiring signal)

TN = true negative (system does not react in situations not requiring signal)

\* = inappropriate alarms treated as TP

System	Total # of Detects	Inappropriate #	Inappropriate %
System 'B'	76	42	55
System 'D'	93	57	61
System 'G'	93	78	89

Figure 8.1-2: Inappropriate Alarms

All of these alarms occurred when the relative speed between the sensor vehicle and the object detected was below 24 KPH. It is evidently a difficult process to reject ground clutter at low differential speeds, most likely due to the noise inherent in the system's determination of the target's speed. When the differential speed is high this noise is irrelevant.

A set of functional goals were established in task 2 of this project. Insofar as the systems tested thus far are concerned, they meet only a narrow subset of those goals. Specifically all but one of the systems are blind spot detectors, as was previously mentioned. This function serves only the first functional goal which is to warn the driver of vehicles immediately adjacent to the subject vehicle. The goal of warning the driver of any fast approaching cars (Goal #3) is only attempted by System D. This system looks approximately 20m behind the subject vehicle. However no system looks forward in the adjacent lane to a similar distance to warn of slow vehicles. The technology for tracking multiple targets that might be required for some of the other lane change/merge goals is simply not in sight at a cost that would be appropriate for automotive applications.

## 8.2 Backing Systems

The two systems in the category of providing warnings to the driver are both ultrasonic. Both were found to be extremely sensitive and prone to false alarms. Backing systems suffer from orthogonal requirements. On the one hand one doesn't want the system to go off all the time, while on the other hand one would like to be sensitive to small targets, such as children, in an environment with a large amount of ground return. A similar table to that for lane change/merge is shown in Figure 8.2-1. Although it would appear that the TN value corresponds to system performance, there is not really enough diversity of systems tested to make a strong case. Both systems exhibited a large number of false positives and in practice required constant monitoring. It is tempting to attribute these difficulties to the inherent problems of ultrasonic systems, but there is insufficient experience to justify such a statement. If one examines the microwave radar systems for lane change/merge, there is a vast range of performance. Making a

Figure 8.1-2

## Road Test Statistics - Backing Systems

System	Test Duration (min)	Latency Time (sec)	Persistence Time (sec)	Total # of detects	TP	FP	FN	TN (%)
System "S"	82.15	0.23	0.46	37	14	23	0	99.8
System "R"	74.5	0.36	0.52	280	20	260	0	97.7

TP = true positive (system reacts in situations requiring signal)

FP = false positive (system reacts in situation not requiring signal)

FN = false negative (system does not react in situations requiring signal)

TN = true negative (system does not react in situations not requiring signal)

decision based upon a limited subset of that technology might lead one to the wrong conclusion.

With respect to the functional goals of a backing system, neither of these two systems meets any of the requirements. Even for near zone detection both systems have a maximum range of about 3m, not the 5m called for in the task 2 report. Although this may seem like a small price to pay, simulations have shown that systems with range out to 5m can achieve a crash avoidance potential in excess of 90%.

### 8.3 Video Systems

The two video systems tested appear to be quite capable of extending the drivers field of regard. The contrast compression may obscure some targets under certain lighting conditions, but such a condition was not observed during these tests. The field of view of both systems provided adequate coverage toward the rear of the vehicle. These two systems are quite capable of satisfying the target detection functional goal. Obviously they cannot satisfy the warning requirement. Though technically feasible, video based collision warning systems require extensive processing which this team feels would be too costly for near-term production.